



Critical Emissions from the Largest On-Road Transport Network in South Asia

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ABSTRACT

One of the major requirements of air quality management for a particular region or country is to understand the sources of emissions, particularly those from the dominant sectors. The on-road transport sector is one of the most important sources of pollutant emissions, as it is directly linked to economic growth, and the current study focuses on India, a nation that is currently experiencing very rapid development. In view of this, the present work develops an inventory of on-road vehicular emissions at $0.5^\circ \times 0.5^\circ$ resolution (approx. 55 km) for a region in India, where a technologically-based dynamic emissions factor method has been used to for the last 20 years. This new inventory can not only provide improved estimates of emissions in recent years but also highlight the relative contribution of various vehicles, based on age, to the total emissions produced by the transport sector. In addition, inventories of the major air pollutants for on-road vehicles in India are developed for the base year of 2009 for the first time in this work. The total emissions from the transport sector are estimated to be 5.4 Tg/yr for NO_x, 10.2 Tg for CO, 693.3 Gg/yr for PM and 5.54 Tg/yr for VOC, 240,000 kilometers of national, state and major highways in India are used to achieve a better spatial allocation of gridded on-road emissions, along with a vehicular density map in a GIS environment. The emissions data presented in this work will not only help in improving the simulated distribution of air pollutants in chemical transport models, but can also be used for air quality management in planning related mitigation strategies.

Keywords: Critical Emissions; on-road transport; Pollutants; India; GIS.

INTRODUCTION

Emission inventories are essential component to our understanding of air quality and climate change issue on regional to global scales (Parrish, 2006). On-road transport sector is one of the prominent sources of emission. In recent decades, number of vehicles in Indian road has grown rapidly due to fast economic development as well as urbanization. However, the economic boom was accompanied by an overall decline in air quality (Cai, 2007; Kaushar *et al.*, 2013). India is a developing country and vehicle emission controls are implemented after 2000 in different stage all over the country. In last two decade, the vehicle number has increased by more than five folds (i.e., 21 million in 1991 to 114 million in 2009) (MoRTH, 2011). With rising transport demand, India became 7th largest vehicle producing country in the world (OICA, 2010). Around 80% of passenger and 60% of freight movement depend on road transport (MoF, 2000). It has been reported that steep increase in vehicle number and poor emission control practices results

in serious air pollution problem (Guo *et al.*, 2007a). On-road vehicles were believed to be the single largest source of major atmospheric pollutants till 1998 (e.g., USEPA, 2000; Pokharel, 2002) and continued to remain a large source especially in developing country. Emission of airborne pollutants from transport sector accounts more than 50% of gross emission in urban as well as semi-urban areas (e.g., Gujar *et al.*, 2004; Fu, 2004; Wang *et al.*, 2005; Zhang *et al.*, 2008; Ramachandran and Shwetamala, 2009; Sahu *et al.*, 2011). Thus an exact estimation of emission from on-road vehicle is crucial to understand the air quality in Indian territory. It is well established that on-road vehicle emissions are perhaps the most important sector in India but they are difficult to quantify as the emission depend on vehicle technology, emission control level, emission factor and age of vehicle. Hence, it is important to develop a high resolution gridded EI of transport sector, but such studies are in sparse for Indian transport sector and hence there is an urgent need to develop high resolution inventories with an improve spatial distribution. In order to have a better monitor and control of air pollution, it is essential that the sources of pollutants are specially distributed which is essential for air quality and chemical transport modeling (CTM) over India subcontinent. Till day, a few studies (e.g., Reddy *et al.*, 2001; Garg *et al.*, 2006; Ramachandra

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and Shwetmala, 2009) were carried out with a top-down approach or broader level estimation (state wise) for base year 2004 which can only be used for making policy but can not be used for scientific modeling study. Moreover, spatially distributed vehicular emission inventories of major pollutants like NO_x, CO, PM and VOC for base year 2009 were never established using a dynamic emission factor, age and technological specific vehicle number and dense road network of major road to allocate emission.

In the present study, vehicular emission inventory has been developed by using technology based dynamic emission factors for latest possible base year 2009 where a better understanding of changing emission norms in India, detailed technology renewal, vehicle age, prepared major road network have been incorporated to generate the gridded format to support model. As emission factor changes with technology, age and vehicle emission norms, as dynamic emission factors could improve the on-road vehicle emission estimation especially in developing country like India. New vehicle emission control standards can reduce emission factors of new vehicle significantly. On the other hand, vehicle's deterioration with age increases emission factors of specific old vehicle model too. This is the first time that a high resolution national inventories of vehicle emissions of above list of major air pollutants (i.e., NO_x, CO, PM and VOC) at the smallest possible provincial level (district) as well as grid level are estimated for most recent year. This paper focuses a methodology to describe the spatial distribution of vehicle emissions in a grid using developed dense road network specially developed in GIS environment.

METHODOLOGY

National vehicle emission control standards along with deteriorated vehicle are two important aspects that affect emission factor. The emission estimates varies considerably over the past 20 years in India. On-road vehicle emission depends on important factors like vehicle emission control, vehicle type, age of vehicle and Vehicle Kilometer Traveled (VKT). So, to establish an refined emission from transport sector, a technology based dynamic vehicular emission factors are applied on vehicle types and their corresponding VKT. A bottom-up approach is adopted to calculate the emission of different pollutants at grid level as well as district level using technological vehicle classification, corresponding dynamic emission factor and annual VKT.

Emission Estimation

The present work adopted the “bottom up” approach which not only improve the accuracy and reliability but also minimize the uncertainty. All emissions were estimated on the basis of activity data at district level as well as grid level. The district level emission from transport sector were estimated based on technology specific vehicular EFs for India (e.g., ARAI, 2007; CPCB, 2010). The technology based age specific vehicle categories are calculated for each district using multiyear registered database and corresponding dynamic emission factor were applied to the vehicle number

along with VKT to obtain the total emission from a district. The detailed formulation is discussed elsewhere and used by us (Sahu *et al.*, 2011) and also included by Bond *et al.* (2004). The total emission is estimated using Eq. (1). EFs are derived by using information of existing vehicular technology based on time to time implemented emission norms. There are then applied to the vehicle numbers and VKT.

$$E_t = \sum (Veh_l \times D_l) \times EF_{l,km} \quad (1)$$

where,

E_t = Total Emission of compound

Veh_l = Number of Vehicle per type

D_l = Distance traveled in a year per different vehicle type

$EF_{l,km}$ = Emission of compound, vehicle type per driven kilometer

Vehicle Registration Distribution and Their Age

Vehicular emissions of particular pollutants vary from category to category due to difference in emission factor, age group, VKT and their population. Distribution of vehicle is very important for the development of emission inventory. The actual district level registration vehicle population data was obtained for the base year 2009 for India from government source as well as from online published data (MoRTH, 2011, MoSRTTH DoES). For the classification of vehicle, six vehicle categories are considered in the present study (i) two wheelers (2W), (ii) auto rickshaws (3W), (iii) cars and jeeps including passenger cars and Multi Utility Vehicles (PC), (v) Buses (Bus), (vi) heavy commercial vehicles (HCV), and (vi) light commercial vehicles (LCV). The numbers of vehicles in each category are plotted in Fig. 1(a). As can be seen that dominant vehicle category is two wheelers which mainly uses petrol as fuel. The population of 2W on road in 2009 is found to be 67.9 millions which is huge. In 2W vehicles, 2 strokes scooter and 4 stroke motorcycle contribute nearly 52% and 48% to the total 2W category respectively. In this category, the 10 year old vehicle number is quite large followed by 5 year old vehicles. The 2nd most dominant category in Indian road is cars and jeeps which are used as personal as well as multi utility passenger vehicles as a taxi, etc. Based on the vehicular registration data and the year of implementation of different emission norms the vehicles are classified into different age group which is shown in the Fig. 1(b). It is also assumed that the vehicle register before 1981 is considered to be scrapped. It is found that 2W is the dominant vehicle category among all age groups followed by PC and HCV. In 10 year old vehicle category, 2W, HCV and PC contributes to a large fraction as compared to any other age group.

Average Vehicle Kilometers Traveled (VKT)

VKT is one of the important parameters to calculate the emission from on-road vehicles. For this purpose, collected daily average VKT per vehicle category has been used in the present study to calculate the emission as per the sample survey (Sahu *et al.*, 2011). The sample size of the collected VKT is approx. 52000. The annual total mileage (km) for each category of vehicle is calculated to estimate

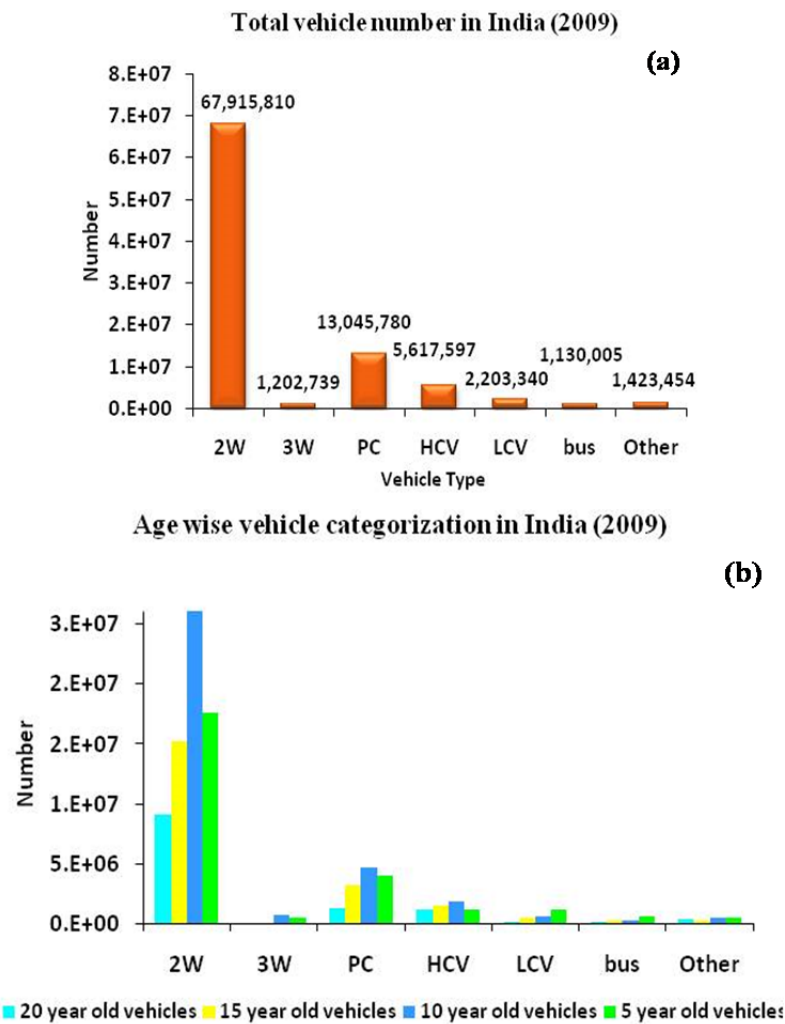


Fig. 1. (a) Technological division of on-road vehicles in India, (b) Age wise categorization.

total annual emission. The VKT used in the present work is shown in Table 1. The VKT for two wheeler, personal and small vehicles travel in small cities have been reduced by 10% with assumption that on road transport system is always in demand due to unavailability of good public transport system in most of cities and semi-urban regions. Moreover the commuters from urban/semi-urban to villages use 2W/3W and small size vehicle and vehicles are always over utilized. These kinds of vehicles may travel little less than as in major cities. It is assumed that in India Heavy Commercial Vehicles including goods-vehicles and tractors use diesel as fuel, motorcycle use gasoline, cars use diesel and gasoline as fuel. In states like Delhi, Mumbai it has been found that 5% of cars and majority of buses use CNG as a fuel which has been considered while estimating the total emissions from these areas.

Spatial Allocation of Emission in GIS Environment

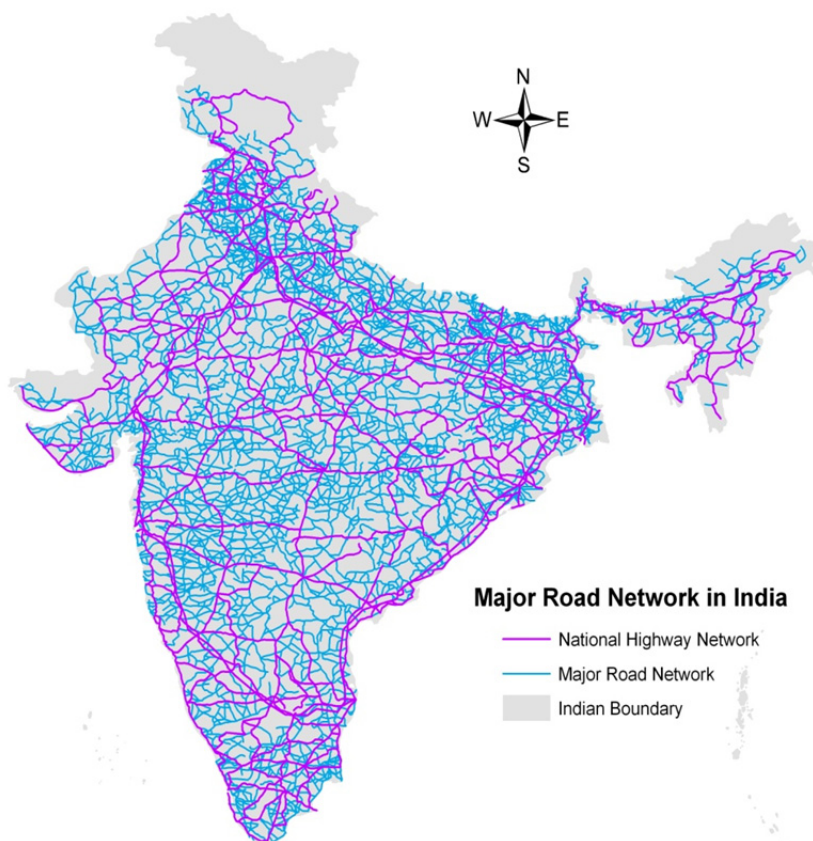
Indian geographical region consist of 593 districts which is the smallest possible sub-region where registered vehicle data is made available recently. Geographically it is covered by 1420 grid cells, each having $0.5^\circ \times 0.5^\circ$ (Approx. 55 km) resolutions. It is assumed that the distribution of on-road

emission depends on important parameters in the district level emission, vehicular population density as well as the length of road network inside a district. Grid of $0.5^\circ \times 0.5^\circ$ resolution cells covering Indian geographical region, district boundary and major road network (national, state and major road network) were prepared by manual digitization using GIS tools. For the road network development, a road network of 2.4 lakhs kilometer is digitized manually using ARCGIS tools. Major road network density in each grid box is calculated from the national road data to allocate the emission from commercial and diesel driven vehicles. Whereas the two-wheeler and other personal vehicle emission allocated to grid cell/district based on grid level vehicular density. Gridding of emissions can be done by overlaying the facility location layer with the grid cell layer and aggregating the facility in each cell. It is a process to transform large and irregularly shaped emission data to uniform data using GIS tools. The emission value for the gridded cells based on the corresponding contribution from different sources lying inside the grid cells is calculated in GIS environment. Prepared dense major road network along with its sub-classification of the roads like national highways, major road and Indian boundary as demarked in Fig. 2.

Table 1. VKT for different vehicle types.

Sr.No.	Vehicle category	Fuel used	New (km/day/vehicle)
1	Two wheelers	Petrol	75
2	Auto Rickshaws	Petrol	120
3	Four Wheelers	Petrol/Diesel	90
4	Buses	Diesel/CNG*	210
5	Taxis	Petrol/ Diesel/CNG*	120
6	Goods Vehicles	Diesel	150

* Delhi, Mumbai.

**Fig. 2.** Major road networks in India.

DYNAMIC EMISSION FACTORS ESTABLISHMENT

As the improvement in emission control standards can reduce the emission in new vehicles. Selection of appropriate emission factor (EF) is a very sensitive part in development of emission inventory. With time and new technology, the vehicle emission standards keep changing to control the emission. Old vehicle have high emission as compared to new vehicle with better emission standard. A dynamic emission factors can represent better scenario of transport emission, especially in the developing country like India. Bharat Stage (BH)-I, BH-II, BH-III and BH-IV are the emission standards which have been implemented periodically in various Indian cities as well as in countrywide during past decade. The year of nationwide implementation of these standards are given in Table 2. A summary of all the dynamic

EFs for different pollutants like NO_x , CO, PM and VOC is provided in Table 3. These are the best estimate available so far for India based on number of reports and experiments conducted by automotive vehicle emission regulatory and certification agencies of government as well as government authorized non-government and autonomous agencies under various projects (CPCB, 2010, HEAT, ICLEI Local Government for sustainability, ARAI, 2007). The present dynamic EFs changes with years in last 20 years as compared earlier version which remains constant thought the years. Although many uncertainties continue to remain due to the sensitivity of EFs to inventory preparation but present effort is towards the best possible estimate. It is based on up to date knowledge and scientific understanding. The Table 3 clearly indicates that the emission from various vehicle age groups is decreasing order with new technology as well as improves in fuel quality.

Table 2. Different Vehicle Emission Norms in India.

Implementation of emission norms in Metropolitan cities					
BS-I vehicles		BS-II vehicles	BS-II vehicles	BS-III vehicles	BS-IV
4W	2000*	2001#	2003**	2005*	2010*
Nationwide implementation of Indian Emission Standards					
Vehicle Type		India 2000	BS-I	BS-II	BS-III
1	Cars & Four wheelers	2000		2005	2010
2	Two wheelers & Auto rickshaws	2000		2005	2010

Source: Auto Fuel Policy, MoPNG, Govt of India (2003). Note: BS: Bharat Stage.

* Implimented in 11 cities: Delhi, Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Agra.

Implimented in 4 cities: Delhi, Mumbai, Kolkata, Chennai.

** Implimented in 7 cities: Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Agra.

Table 3. Technological Emission Factors for Transport Sector.

Pollutant	Model year	S (2S)	S (4S)	M (4S)	3w	PC	LCV	HCV	Bus	Other
		Petrol	Petrol	Petrol	Petrol	Petrol	Petrol	Diesel	Diesel	Diesel
PM	2006–2010	0.04	0.02	0.01	0.05	0	0.48	0.42	0.3	0.42
	2001–2005	0.05	0.02	0.04	0.05	0	0.48	1.24	1.08	1.24
	1996–2000	0.07	-	0.02	-	0.01	0.66	1.97	1.21	1.97
	1991–1995	0.07	-	0.01	-	0.01	1	1.97	2.01	1.97
CO	2006–2010	2.37	0.4	0.72	1.37	0.84	3.66	4.13	3.92	4.13
	2001–2005	2.37	0.93	1.65	1.37	1.3	3.66	6	3.97	6
	1996–2000	5.1	-	1.58	-	4.53	3	19.3	4.48	19.3
	1991–1995	6	-	3.12	-	4.75	3.07	19.3	13.06	19.3
NO _x	2006–2010	0.02	0.25	0.15	0.2	0.09	2.12	8.63	6.53	8.63
	2001–2005	0.03	0.35	0.27	0.2	0.2	2.12	9.3	6.77	9.3
	1996–2000	0.01	-	0.3	-	0.75	2.48	13.84	15.25	13.84
	1991–1995	0.02	-	0.23	-	0.95	3.03	13.84	11.24	13.84
VOCs*	2006–2010	0.59	0.59	0.59	0.01	0.14	0.01	0.85	0.85	0.85
	2001–2005	2.03	2.03	2.03	0.01	0.24	0.01	0.85	0.85	0.85
	1991–2000	4.31	4.31	4.31	-	1.88	0.01	1.97	1.97	1.97

Source: CPCB (2010); ARAI (2007); * HEAT, ICLEI Local Government for sustainability.

Note: S (2S): Two Stroke Scooters; S (4S): Four Stroke Scooters; M (4S): Four Stroke Motorcycles; 3W: Three wheelers (Auto rickshaws); PC: Passenger Cars; HCV: Heavy Commercial Vehicles; LCV: Light Commercial Vehicles.

RESULTS

The spatial allocations of on-road transport emission in India have been gridded at $0.5^\circ \times 0.5^\circ$ resolution. This resolution is found to be best possible and sufficient to provide information regarding all emission patterns on a finer scale.

Spatial Distribution of NO_x and CO Inventory

The spatial distribution of estimated total NO_x and CO emissions in Gg/yr per box of ($0.5^\circ \times 0.5^\circ$) from on-road vehicle source during 2009 as obtained in this work are shown in Fig. 3(a) and Fig. 4(a) and their relative contribution from different vehicle type is provide in the form of pi-chart in Fig. 3(b) and Fig. 4(b) respectively. The total NO_x and CO emission is found to be 5.4 Tg/yr and 10.2 Tg/yr respectively. A maximum emission of the order of 50–200 Gg/yr of NO_x and 100–480 Gg/yr of CO is found over the upper Indo-Gangatic Plain (IGP) area (marked in red in Fig. 3(a) and Fig. 4(a)), some parts of Western and Southern tip

of Indian geographical region. The high emission in the above regions is due to high population density is always associated with more demand of HCV, bus and two-wheelers. Both the figure illustrates clearly that the emission density in upper IGP and western region are much higher than those in eastern, central and northeastern part of India. A dense road networks drives the large vehicle movements in the above region (as show in Fig. 2). IGP region accounts nearly 15% of the total Indian geographical area but contributed around 39% of the total NO_x (around 2113 Gg/yr) and 35.4% of total CO (around 3.6 Tg/yr) emission from on-road transport in India. This indicates that high population density drives HCV followed by bus is responsible for NO_x emission whereas two wheelers (2W) followed by HCV responsible for CO emission. This is mainly due to the fact that NO_x has very high EFs for HCV and bus whereas CO has high EF for 2W. It is also found that transport network is also found to be very dense in IGP, southern and western India. The industrial cities in above region drive people to migrate from surrounding to above

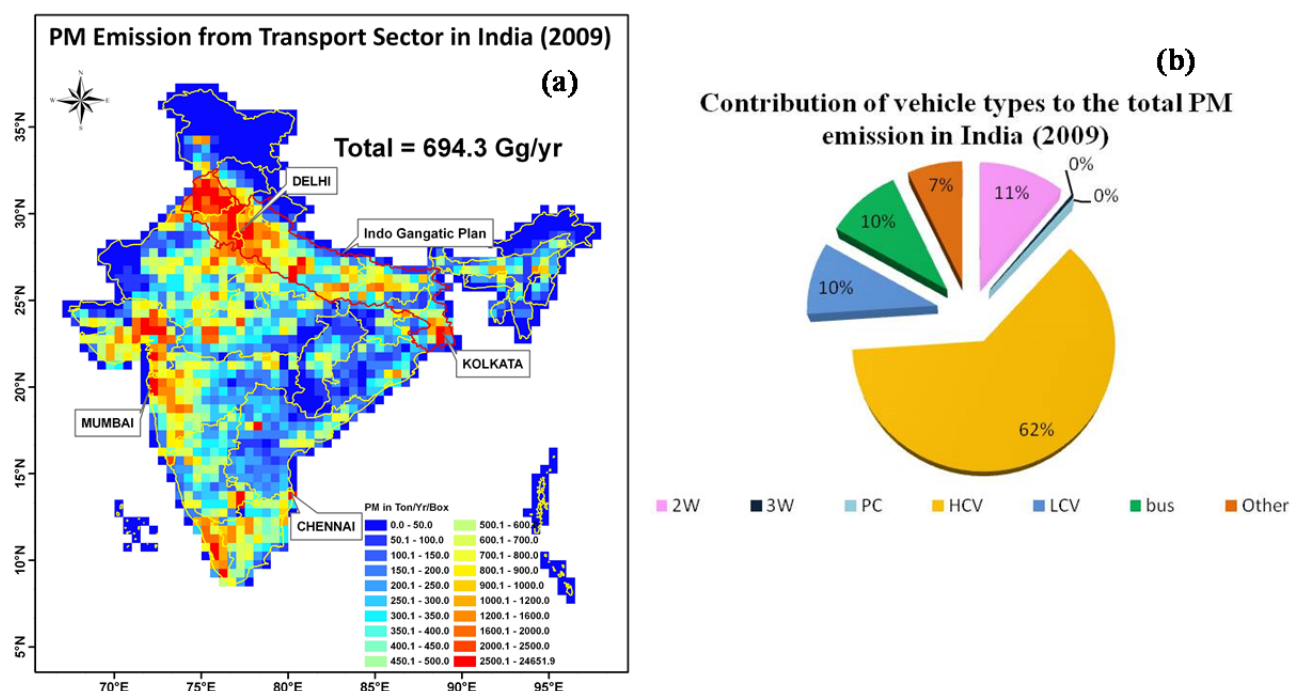


Fig. 3. (a) Gridded NO_x emissions from on-road vehicle in India (2009), (b) Relative contribution from different vehicle category.

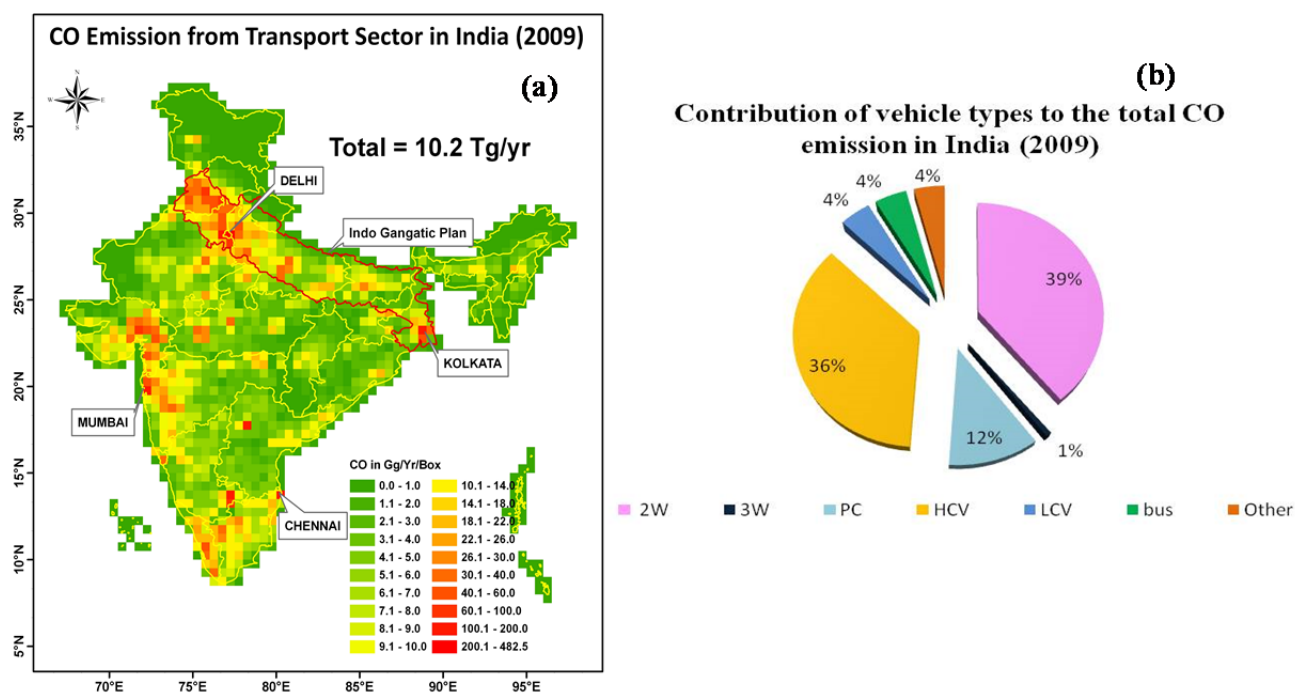


Fig. 4. (a) Gridded CO emissions from on-road vehicle in India (2009), (b) Relative contribution emission from different vehicle category.

regions which are one of the important factors driving high emission. The discussed high emitting regions covers nearly 21–25% of India's territory, but were responsible for over 69% of the NO_x and 73% of CO emissions, with the remaining emissions distributing over the other remaining large geographical region (approx. 79–75%) which includes

Central, Northwestern, Northern-Eastern, Eastern part of Central India etc.

Emission as low of 1–5 Gg/yr of NO_x and 1–8 Gg/yr of CO is found in Northwestern, Central, Northern-Eastern, Eastern part of Central India. It indicate that on-road vehicular emission in India were not only large in quantities,

but were rather unevenly distributed where the emission intensity in grid changes from an order of 1 to 50. A grid level analysis shows that just 10% of grid (142) contributes 50.4% of NO_x and 49% of CO emission. All well known major cities along with emerging medium/small towns become the source of high NO_x and CO emission. District level analysis shows that only 10% of the total districts contribute more than 2.41 Tg/yr (i.e., 44.6%) of total Indian NO_x and 4.71 Tg/yr of CO (46.2%). On the national scale, relative contribution of NO_x emission from different vehicle category shows that emission from HCV (63%) dominate followed by bus (13%) as shown in Fig. 3(b) as compared to 2W (39%) followed by HCV ((36%) and personal vehicles (12%) in the case of CO emission (Fig. 4(b)). The difference in EFs drives the change in relative contribution from NO_x to CO.

Spatial Distribution of PM and VOC Inventory

The emission of PM and VOC were calculated to be 694.3 Gg/yr and 5.54 Tg/yr for year 2009. Their spatial distribution emission intensity in gridded form along with relative contribution of emission from different vehicle categories are shown in Figs. 5(a) and 5(b) for PM and Figs. 6(a) and 6(b) for VOC respectively. The spatial distribution of above pollutant concentration shows an uneven distribution pattern where the pollutant concentration decreases from peak emission in high upper IGP, southern and western regions to central as well as eastern India. Fig. 5(a) and Fig. 6(a) illustrates clearly that emission densities in upper IGP, southern, western regions and some part of northern-west regions were much higher (i.e., 1200–24000 ton/yr for PM and 30–280 Gg/yr for VOC) than those

central, eastern and northern-east parts (i.e., 50–250 ton/yr for PM and 0.5–4 Gg/yr for VOC). A high road network associated with high population density drive more vehicle activity in above regions which directly or indirectly intensify emissions. IGP region accounts 38.1% of the total PM (around 264 Gg/yr) and 32.6% of total VOC (around 1.8 Tg/yr) emission. More productive agriculture land in IGP is considered as most densely populated region in India. This dense population drives more number of two wheeler vehicle for personal use which is major reason of VOC emission in this region. However, HCV emits large fraction of PM emissions in IGP. The high emission in southern and western region is associated with rapid economic development in these regions like industrial activity which make the people to migrate from rural regions. Relatively lower values of PM (50–250 ton/yr) and VOC (0.5–4 Gg/yr) emissions are found over the Eastern and Central India and lower IGP belts. This could be attributed due to the presence of large forest cover, low population density and large rural areas. Generally, the vehicular related activity is found to be very high in urban and semi-urban cities. All the cities became source of large amount of emission of PM as well as VOC. The four major cities producing most vehicular emission were Delhi, Mumbai, Chennai and Kolkata, which cover merely 1% of Indian territory, but were responsible for about 9% of total PM and 11% of total VOC emission.

The district level range analysis shows a diverse spatial distribution where the most emitting 59 districts (10%) contribute around 308.5 Gg/yr (44.4%) of PM as compared to 2.8 Tg/yr (51%) of VOC to total Indian emission. Range analysis shows that 10% of Indian districts contribute more

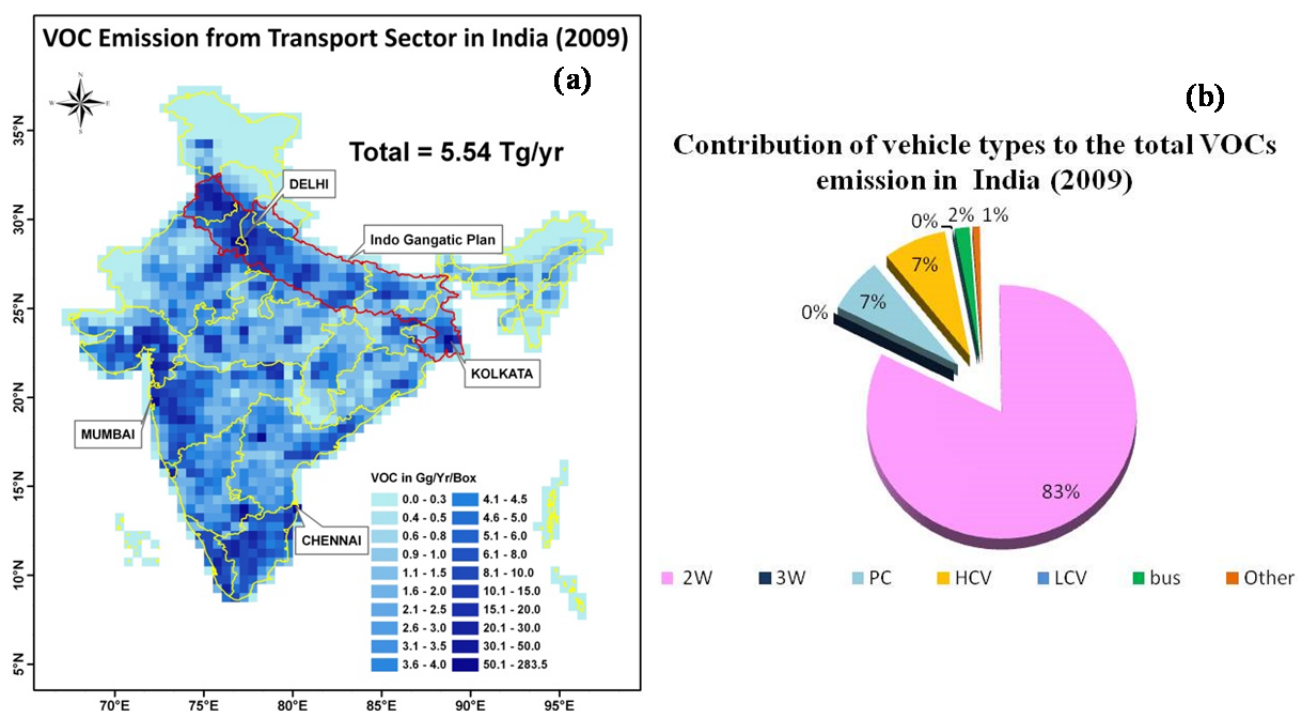


Fig. 5. (a) Gridded PM emissions from on-road vehicle in India (2009), (b) Relative contribution from different vehicle category.

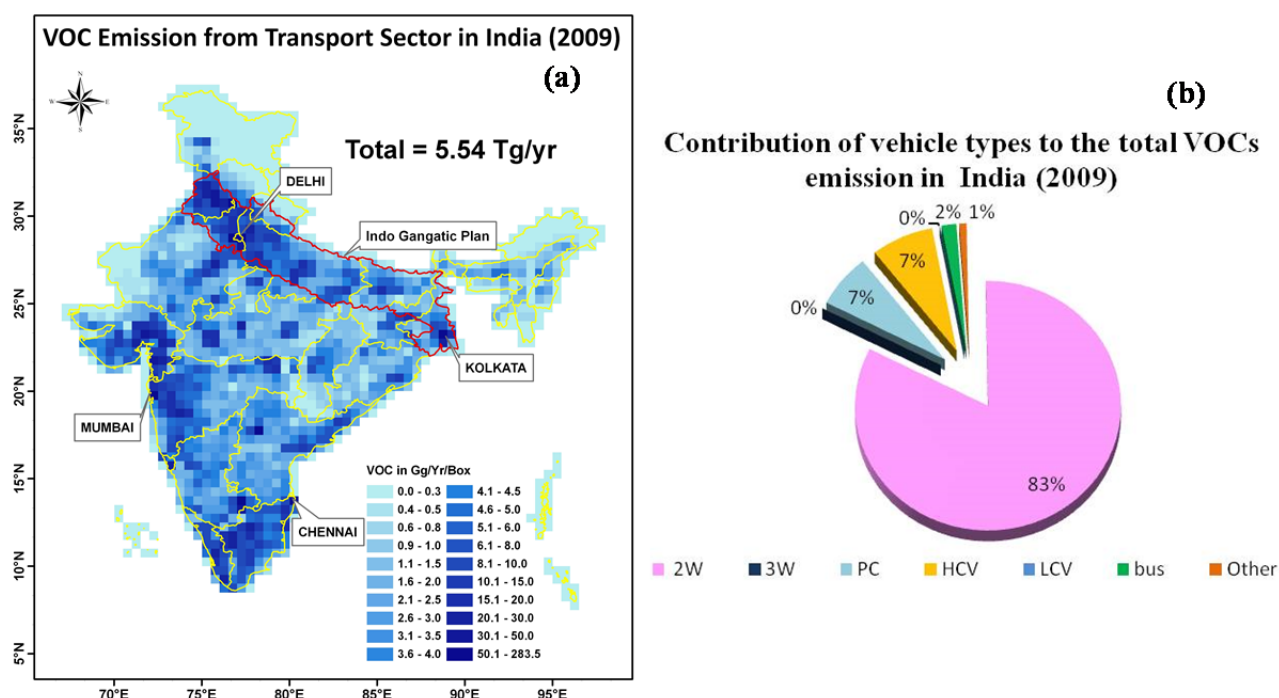


Fig. 6. (a) Gridded VOC emissions from on-road vehicle in India (2009), (b) Relative contribution from different vehicle category.

then 49% of PM and 52.7% of VOC. Grid level range analysis shows that only 10% grid boxes of high emissions contribute more than 345.5 Gg/yr (44%) of PM and 2.9 Tg/yr of VOC. Fig. 5(b) and Fig. 6(b) shows that the principal contributor to PM and VOC emissions were HCV (62%) and two-wheeler (83%) respectively, mainly due to the high emission factors of above vehicle type.

Contribution of Each Vehicle Category to Emissions

Results obtained for Indian on-road emission inventories have been studied in comprehensive and consistent way for the base year 2009. On-road vehicle contribution to the emission of particular pollutants varied from category to category, due to different levels of emission factors of the pollutants. To reduce emissions effectively, it is necessary to check out the emission distribution of each vehicle category first. Fig. 7 shows estimated total emission of all discussed pollutants from on-road vehicles during 2009 and their relative contribution of emission from different technological distributed age groups like 5 yrs, 10 yrs, 15 yrs and 20 yrs respectively. Fig. 7 shows that the 15 yr old vehicles are responsible for maximum emission of NO_x and CO to total estimation. Large number of 20 year and 15 year old HCV, bus as well 2W vehicle are responsible for large fraction PM and VOC emission in India. The spatial distributions of above pollutants in the gridded form were discussed in the next paragraph to follow. The principle cause for the intensifying pollution must be ascribed to the booming population of vehicle of 10–15 year old after mid 1990s. We can say that India's rapid economic growth has stimulated the increase of vehicle population which generated a large amount of emissions.

This could be warning in the present scenario but with improve of technology and introduce of efficient vehicle will replace the old vehicle in coming decades (2010s) which will reduce the emission to greater extend.

Inter-Comparison with Global and National Estimations

It is difficult to compare the present estimated emission from transport sector for 2009 with widely used estimation by global researches like Ohara *et al.* (2007) and Zhang *et al.* (2009). As there estimations for 2006, 2010 were given in gross for India. However, present result is compared with sector specific estimation by Ohara *et al.* (2007) for 2000. The present estimated NO_x for 2009 is 5.4 Tg/yr which is quit high as compared to estimation made for 2000 by Ohara *et al.* (2007). The reason could be due to increase in number of old vehicle (10–20 years) segment with time. Similarly, our CO estimation of 10.2 Tg/yr in 2009 is just 30% higher than the estimation made for 2000. The main reason could be due to the rise in personal vehicles as well as two-wheeler segment in recent time. More improved version of petrol vehicle is restricting the large emission as the EFs for the same is very low.

CONCLUSION

A high resolution emission inventory with their spatial allocation for Indian on-road transport emission has been achieved in the present work which is essential for chemistry transport modeling. A technology based dynamic emission factor based approach was followed for a better understanding of changing emission norms with time in India. The on-road vehicle emissions of NO_x , CO, PM and

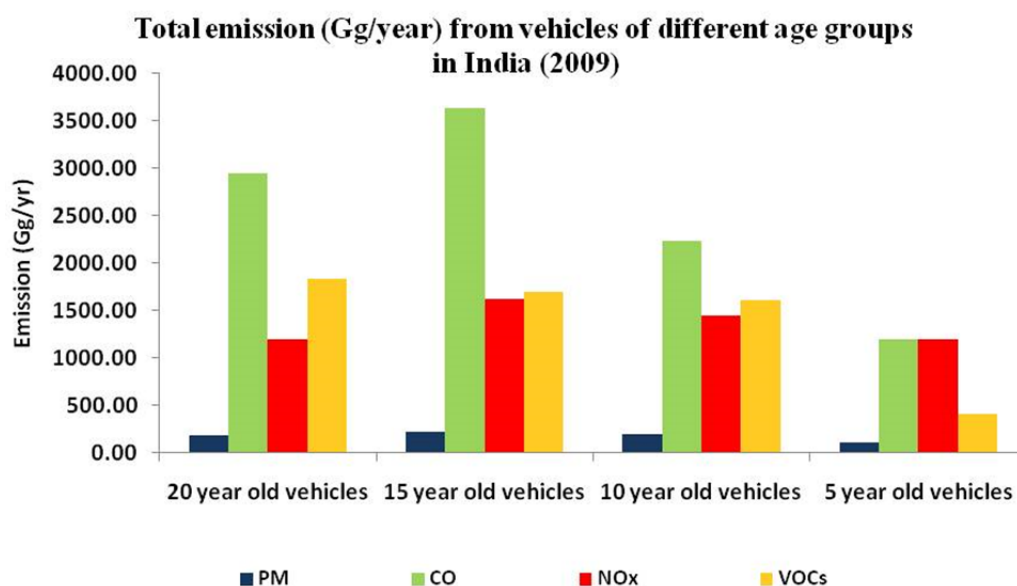


Fig. 7. Relative contribution of emission from various technologically Vehicle age group.

VOC during 2009 are found to be 5.4 Tg/yr, 10.2 Tg, 693.3 Gg/yr and 5.54 Tg/yr respectively. Vehicles of different age groups having different existing technologies responsible for high emission are also identified which could be used to implement mitigation strategies as well as to support chemical transport modeling study. Phase out of vehicle more than 20 year old commercial vehicles along with improvement in road condition in cities and semi-urban can be used as long term control Strategies to minimize the emission to great extent. Moreover, an improved public transport system will further discourage the use of personal vehicle in cities and semi-urban regions. The present work not only able to highlight the hot-spot for various pollutants across the Indian domain but also assesses the efficiency of long term control strategies for various cities.

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